

**APPLICATION
FOR
UNITED STATES PATENT**

**TITLE: Continuously Variable Transmission Fluid and Method of Making
 Same**

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CONTINUOUSLY VARIABLE TRANSMISSION FLUID AND METHOD OF MAKING SAME

PRIOR RELATED APPLICATIONS

5 [1] This patent application claims priority to U.S. Provisional Application Serial No. 60/414,894 filed on September 30, 2002, entitled "Continuously Variable Transmission Fluid and Method of Making Same," which is incorporated by reference herein in its entirety.

FEDERALLY SPONSORED RESEARCH STATEMENT

[2] Not applicable.

REFERENCE TO MICROFICHE APPENDIX

10 [3] Not applicable.

FIELD OF THE INVENTION

[4] This invention relates generally to transmission fluids for use with continuously variable transmissions (CVT), also referred to as traction drives.

BACKGROUND OF THE INVENTION

15 [5] Continuously variable transmissions (CVT), also known as traction drives, represent a radical departure from conventional automatic transmissions. The push belt version of the CVT was invented by Dr. Hub Van Doorne, and since its introduction, many cars have been equipped with the push belt CVT system. CVT push belts are manufactured by Van Doorne's Transmissie VB of Tilburg, the Netherlands. A more detailed description of such transmissions and belts and lubricants employed therein is found in U.S. Patent No. 5,750,477 and the references cited therein. In brief, a belt and pulley system is central to the operation of this type of transmission. The pulley system comprises a pair of pulleys with a V-shaped cross-section, each consisting of a moveable sheave, a fixed sheave, and a hydraulic cylinder. Between the
20 pulleys runs a belt which consists of a set of metal elements held together by metal bands. In
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operation, the driving pulley pushes the belt to the driven pulley, thereby transferring power from the input to the output. The transmission drive ratio is controlled by opening or closing the moveable sheaves so that the belt rides lower or higher on the pulley faces. This manner of operation permits continuous adjustment of gear ratio between the input and output shafts.

5 [6] It has become clear from commercial use of CVT that the fluids used in the CVT are just as important as the mechanical design for satisfactory operation. The lubricant should fulfill several functions: to lubricate the metal belt in its contacts with the pulley assembly, the planetary and other gears, the wet-plate clutches, and the bearings; to cool the transmission; and to carry hydraulic signals and power. The hydraulic pressure controls the belt traction,
10 transmission ratio, and clutch engagement. Accordingly, the fluid should maintain a relatively high coefficient of friction for metal/metal contact, as well as exhibiting a suitable degree of shear stability.

 [7] While the working elements of a traction drive are sometimes spoken of as being in contact, it is generally accepted that a fluid film be provided therebetween. Thus, rather than
15 metal-to-metal rolling contact, a film of fluid is introduced into the load zone, and power is transmitted by shearing of the film, which may become very viscous due to the high pressure at the contact area. The nature and properties of the fluid, therefore, determine to a large extent the performance and capacity of the traction drive. Traction fluids preferably have a high shear resistance (often measured as "traction coefficient") to maximize the power transmission
20 performance. Low viscosity, particularly at low temperatures, is also desirable for efficient operation under cold conditions. The fluid should ideally also exhibit good lubricating properties for and compatibility with other components of the traction drive. Such fluids also serve to remove heat and prevent wear at the contact surfaces and to lubricate bearings and other moving parts associated with the drive.

25 [8] So far, various different traction drive fluids have been developed and disclosed. See, for example, U.S. Patents No. 6,372,696; No. 5,422,027; No. 6,262,000; No. 6,451,745; and No. 6,103,673. However, it is often the case that some compounds having a high traction coefficient at high temperatures cause a relatively large churning loss because of the high viscosity, thus resulting in low transmission efficiency, but also having relatively poor capability to

start traction drive units at low temperatures. On the other hand, other compounds of low viscosity and therefore high transmission efficiency have a relatively low traction coefficient at high temperatures and their viscosity decreases with increasing oil temperature too much, causing trouble with respect to lubrication in traction drive units. Therefore, there is a need for a traction
5 fluid or a CVT fluid with a relatively high traction coefficient and good low temperature properties, such as viscosity and shear stability.

SUMMARY OF THE INVENTION

[9] Embodiments of the invention meet the above need in one or more of the following aspects. In one aspect, the invention relates to a continuously variable transmission (CVT) fluid
10 with a relatively high traction coefficient and good low temperature properties. The CVT fluid comprises or obtained by mixing a hydrogenated cyclic dimer of α -alkyl styrene and a low temperature viscosity control agent, wherein the fluid comprises less than about 20 wt.% of a linear dimer of the α -alkyl styrene. Preferably, the CVT fluid has a kinematic viscosity of greater than about 2.5×10^{-6} m²/s at 100 °C, as measured according to ASTM D-445. The low
15 temperature viscosity control agent should be present in an amount sufficient to reduce the viscosity of the fluid at -30 °C.

[10] In another aspect, the invention relates to a method of making a dimerized α -alkyl styrene, which can be used as a base oil for a CVT fluid. The method comprises (a) contacting an α -alkyl styrene with a supported acid catalyst under a temperature and pressure condition to
20 effect oligomerization of the α -alkyl styrene to produce a cyclic dimer of the α -alkyl styrene; and (b) hydrogenating the cyclic dimer of the α -alkyl styrene in the presence of a hydrogenation catalyst to produce a fully hydrogenated cyclic dimer of the α -alkyl styrene, wherein the α -alkyl styrene is contacted with the supported acid catalyst in the absence of a solvent for the α -alkyl styrene and in the absence of a free acid. A continuously variable transmission fluid is formulated
25 by mixing the fully hydrogenated cyclic dimer with an oil additive, wherein the continuously variable transmission fluid does not comprise more than 20 wt.% of a linear dimer of the α -alkyl styrene. In some embodiments, the α -alkyl styrene is α -methyl styrene and the cyclic dimer is 1-

cyclohexyl-1,1,3-trimethylhydrindane. The CVT fluid formulated according to embodiments of the invention has a relatively high traction coefficient and good low temperature properties.

[11] Additional aspects of the invention and characteristics and properties of various embodiments of the invention become apparent with the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

[12] Not applicable.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[13] In the following description, all numbers disclosed herein are approximate values, regardless whether the word "about" or "approximate" is used in connection therewith. They may vary by 1 percent, 2 percent, 5 percent, or sometimes 10 to 20 percent. Whenever a numerical range with a lower limit, R^L and an upper limit, R^U , is disclosed, any number falling within the range is specifically disclosed. In particular, the following numbers within the range are specifically disclosed: $R=R^L+k*(R^U-R^L)$, wherein k is a variable ranging from 1 percent to 100 percent with a 1 percent increment, i.e., k is 1 percent, 2 percent, 3 percent, 4 percent, 5 percent,..., 50 percent, 51 percent, 52 percent,..., 95 percent, 96 percent, 97 percent, 98 percent, 99 percent, or 100 percent. Moreover, any numerical range defined by two R numbers as defined in the above is also specifically disclosed. Any references cited herein are hereby incorporated by reference, in their entirety.

[14] Embodiments of the invention provides a continuously variable transmission (CVT) fluid with a relatively high traction coefficient and good low temperature properties. The CVT fluid comprises a hydrogenated cyclic dimer of α -alkyl styrene and a low temperature viscosity control agent in an amount sufficient to reduce the viscosity of the fluid at $-30\text{ }^{\circ}\text{C}$, wherein the fluid is comprises less than about 20 wt.% of a linear dimer of the α -alkyl styrene. Preferably, the CVT fluid has a kinematic viscosity of greater than about $2.5\times 10^{-6}\text{ m}^2/\text{s}$ at $100\text{ }^{\circ}\text{C}$, as measured according to ASTM D-445. In some embodiments, the kinematic viscosity is greater than about $3.0\times 10^{-6}\text{ m}^2/\text{s}$ at $100\text{ }^{\circ}\text{C}$, $3.5\times 10^{-6}\text{ m}^2/\text{s}$ at $100\text{ }^{\circ}\text{C}$, $4.0\times 10^{-6}\text{ m}^2/\text{s}$ at $100\text{ }^{\circ}\text{C}$, 4.5×10^{-6}

m^2/s at $100\text{ }^\circ\text{C}$, $5.0 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $6.5 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $7.0 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $7.5 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $8.0 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $8.5 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $9.0 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $9.5 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, or $2.5 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$. It may also be greater than about $10.0 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $11.0 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $12.0 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, $13.0 \times 10^{-6} m^2/s$ at $100\text{ }^\circ\text{C}$, or higher. The CVT fluid can be used as a lubricant in any design of continuously variable transmission, such as the push belt type or the toroidal type. These types of continuously variable transmission are disclosed, for example, in U.S. Patents No. 6,565,478 and No. 5,750,477.

[15] As used herein, the term "in an amount sufficient to reduce the viscosity of the fluid at $-30\text{ }^\circ\text{C}$ " means that the CVT fluid contains from about 1 to about 20 wt% of a low temperature viscosity control agent. In some embodiments, "in an amount sufficient to reduce the viscosity of the fluid at $-30\text{ }^\circ\text{C}$ " means from about 3 to about 15 wt%, or from about 5 to about 10 wt%.

[16] Preferably, the CVT fluid has a relatively high traction coefficient. For example, in some embodiments, the traction coefficient at $100\text{ }^\circ\text{C}$ is greater than about 0.07, 0.08, 0.09, or 0.10. In other embodiments, the traction coefficient at $100\text{ }^\circ\text{C}$ is greater than about 0.101, 0.102, 0.103, 0.104, 0.105, 0.106, 0.107, 0.108, or 0.109. In some other embodiments, the traction coefficient at $100\text{ }^\circ\text{C}$ exceeds about 0.11, 0.12, 0.13, 0.14, or 0.15.

[17] One low temperature property of the CVT fluid is the Brookfield viscosity, which can be measured according to ASTM D 2983, entitled "Low-Temperature Viscosity of Automotive Fluid Lubricants Measured by Brookfield Viscometer," which is incorporated by reference herein in its entirety. Preferably, the Brookfield viscosity at $-30\text{ }^\circ\text{C}$ of the CVT fluid is less than about 100 Pa•s. In some embodiments, the Brookfield viscosity is less than about 90, 80, 70, 60, 50, 40, 30, 20, 10, or 5 Pa•s. Preferably, it is in the range from about 5 to about 70 Pa•s.

[18] As described above, the CVT fluid comprises a hydrogenated dimer of α -alkyl styrene as a base oil. The method for making the hydrogenated dimer comprises (a) contacting an α -alkyl styrene with a supported acid catalyst under a temperature and pressure condition to effect oligomerization of the α -alkyl styrene to produce an oligomerization product, the

oligomerization product comprising a cyclic dimer of the α -alkyl styrene; and (b) hydrogenating the cyclic dimer of the α -alkyl styrene in the presence of a hydrogenation catalyst to produce a fully hydrogenated cyclic dimer of the α -alkyl styrene, wherein the α -alkyl styrene is contacted with the supported acid catalyst in the absence of a solvent for the α -alkyl styrene and the absence
5 of a free acid. A CVT fluid is formulated by mixing the fully hydrogenated cyclic dimer with one or more oil additives (such as a low temperature viscosity control agent), wherein the continuously variable transmission fluid comprises less than about 20 wt.% of a linear dimer of the α -alkyl styrene.

[19] Although the alkyl group of the α -alkyl styrene can be any straight, branched, or
10 cyclic hydrocarbyl group of any carbon number, it is preferred that the alkyl group is a straight hydrocarbyl chain with a carbon number of less than 30. The term "alkyl" used herein refers to an organic group comprising carbon and hydrogen and can have a straight chain, branched chain, or cyclic hydrocarbons from one to about twenty carbons. For example, alkyl includes, but is not limited to, methyl, ethyl, propyl, butyl, pentyl, hexyl, cyclopropyl, cyclobutyl, cyclopentyl,
15 cyclohexyl, methylcyclopentyl, ethenyl, propenyl, butenyl, pentenyl, hexenyl, phenyl, naphthyl, anthracenyl, benzyl, and isomers thereof. In some embodiments, the alkyl group has from 1 to 4 carbon atoms, such as methyl or ethyl. The preferred dimers are accordingly hydrogenated cyclic dimers of α -methylstyrene and α -ethylstyrene, hydrogenated cyclic co-dimers of α -methylstyrene and α -ethylstyrene, and mixtures thereof. Hydrogenated dimer of α -methylstyrene is also called
20 1-cyclohexyl-1,1,3-trimethylhydrindane. The method of making 1-cyclohexyl-1,1,3-trimethylhydrindane is explained in the following. While the synthesis of 1-cyclohexyl-1,1,3-trimethylhydrindane is exemplified herein, the cyclic dimer of other α -alkyl styrene can also be obtained by the following process, with or without modifications.

[20] Dimerization of α -methyl styrene is effected by passing α -methyl styrene,
25 preferably in the absence of a solvent, through a column of an acidic ion-exchange resin under conditions which yield at least 80% of the cyclic dimer, which is followed by fully hydrogenating the product under conditions which convert the cyclic dimer of α -methyl styrene to 1-cyclohexyl-1,1,3-trimethylhydrindane. Optionally, before hydrogenating, the cyclic dimer is vacuum distilled to remove a minor amount of the trimer of α -methyl styrene. Preferably, the acid is supported

such that there is no substantial amount of free acid (i.e., unsupported acid). In other words, the dimerization occurs substantially free of unsupported acid (i.e., free acid). In some embodiments, the dimerization reaction is completely free of free acid.

[21] In one embodiment, the acidic resin is the strongly acidic resin Amberlyst® 15, an acidic sulfonated divinylbenzene/styrene copolymer. The column of resin is operated at a temperature of about 0°C to about 150 °C, a pressure of about 15 to about 44 psig (about 103 to about 303 kPa gauge), and with a residence time of about 1 second to about 200 minutes. Preferably, the column of resin is operated at about 60°C to about 120°C, a pressure of about 15 to about 30 psig (100 to 200 kPa gauge), and a residence time of about 5 second to about 20 minutes.

[22] Hydrogenation of the product of the dimerization column is carried out by contact with a hydrogenation catalyst, preferably palladium on carbon at a temperature of about 120°C to about 220°C preferably about 160°C to about 200°C, for about 4 hours to about 24 hours at a hydrogen pressure of about 500 to about 2,000 psig (3,447 to 13,789 kPa gauge) preferably, about 700 to about 1,000 psig (4,826 to 6,895 kPa gauge). Optionally, the hydrogenated product is vacuum distilled at a pressure of about 0.1 to about 150 mm Hg absolute to remove the fully hydrogenated trimer of α -methyl styrene.

Dimerization Catalyst

[23] The acidic ion-exchange catalysts used in the process of the invention may be considered solid super acids. Sulfonic acid groups are attached to polymers such as divinylbenzene/styrene copolymers, perfluorinated epoxides, and phenolformaldehyde resins. The acidity may be increased by reacting the sulphonated polymers with Lewis acid halides, such as AlCl_3 , SnCl_2 , TiCl_4 , SbF_5 and BF_3 .

[24] The preferred catalyst for use in the dimerization step is the strongly acidic ion-exchange resin, Amberlyst® 15, a product of the Rohm & Haas Company. Alternatively, other acidic supported catalysts could be used, although not necessarily with equivalent results. Examples of such catalysts are Nation®-H, a copolymer of perfluorinated epoxide/vinyl/sulphonic acid made by E.I. Dupont, and strongly acidic ion-exchange resins Dowex-50 made by the Dow

Chemical Company. Alternatively, weakly acidic ion-exchange resin with carboxylic acid functionality could be used, such as Amberlite CG-50 or Amberlite IRC-50S made by Rohm & Haas.

Reactor

5 [25] The acidic ion-exchange resin particles preferably are placed in a fixed bed arrangement in a cylindrical reactor. In some embodiments of the invention, the catalyst is in particulate form and disposed in a fixed bed. Consequently, the mixing of the fresh α -methyl styrene with products is minimized and the conversion of the feed stock into a product, which is almost completely the cyclic dimer, appears to occur by a sequential reaction of α -methyl styrene
10 to the linear dimer, 2,4-diphenyl-4-methyl-1-pentene or the 2-pentene isomer, followed by a Friedel-Crafts reaction to form the cyclic dimer, 1-cyclohexyl-1,1,3-trimethylindane. In the example below, the ratio of the length to the diameter of the resin bed is about 5/1, but it is expected that ratios between about 1/10 and about 20/1 could be used. The size of the resin particles are normally be about 200 mesh to macro-reticular beads.

15 [26] The residence time in the reactor, that is the time when the α -methyl styrene is in contact with the catalyst, is about 1 second to about 200 minutes, preferably about 5 second to about 20 minutes, depending on the desired yield of the product and the temperature chosen for the reaction. In general, a temperature between ambient and about 150°C are used, preferably about 60° to about 120°C, depending on the residence time and desired yield of the cyclic dimer.
20 The operating pressure is about 15 to about 44 psig (100 to 300 kPa gauge), preferably about 15 to about 30 psig (100 to 200 kPa gauge). One familiar with the art understands that a balancing of variables (e.g. residence time, temperature, length/diameter) is usually made to provide the optimum conditions for making the desired yield of the cyclic dimer.

Hydrogenation of the Dimer

25 [27] Since only α -methyl styrene need be supplied to the reactor, the product containing a high yield of the cyclic dimer, of at least 80%, can be immediately fed to a hydrogenation step, although separation of the dimer from the small amount of trimer can be done before the hydrogenation step.

[28] Hydrogenation can be carried out using a known catalyst, such as nickel on kieselguhr, nickel on silica/alumina, Raney nickel, palladium on carbon, platinum and the like. In the example below, palladium supported on carbon is used and found to be effective. If a supported catalyst is used, it typically is placed in a fixed bed reactor and the feed stock passed
5 over it while mixed with hydrogen under suitable hydrogenation conditions. The temperature should be between about 120° and about 250°C, but preferably between about 160° and about 200°C. The pressure of the hydrogen in the reactor is about 5,000 to about 2,000 psig (3,447 to 13,789 kPa gauge), preferably about 700 to about 1,000 psig (4,826 to 6,895 kPa gauge). After a suitable period of time, the cyclic dimer of α -methyl styrene is converted to the fully hydrogenated
10 form in which the phenyl groups of the dimer have been converted to cyclohexyl groups.

[29] After separating the hydrogen, the product may be used directly as the base oil for further formulating a transmission fluid, or it may be purified by distillation to remove the hydrogenated trimer of α -methyl styrene. As will be seen in Example 3 below, the traction coefficient for the hydrogenated product containing about 95% of the cyclic dimer and 5% of the
15 trimer is superior to that of the hydrogenated linear dimer. After removing the trimer, the traction coefficient is further improved.

[30] The above process has one or more of the following advantages. In a once-through catalytic reaction in a fixed bed reactor, α -methyl styrene is converted to at least 80% yield of the cyclic dimer. The product can be immediately converted to the fully hydrogenated
20 form and used as the base oil for further formulating a transmission fluid, or alternatively, it can be distilled to remove the minor portion of the trimer of α -methyl styrene and then hydrogenated. The trimer also may be removed by distillation after the hydrogenation step. No diluents are needed in the dimerization step, the α -methyl styrene being supplied in commercially pure form. Thus, separation of diluents from the product of the dimerization reaction is not needed and no
25 aqueous washes are required. The hydrogenation product containing the trimer of α -methyl styrene has a traction coefficient greater than that of the hydrogenated linear dimer and the traction coefficient is further improved by separation of the trimer.

[31] While the above processes are described in detail, the process conditions can vary. For example, the processes can be modified by practicing the dimerization and hydrogenation

steps disclosed in the following U.S. patents which are incorporated by referenced herein in their entirety: 2,629,751; 3,411,369; 3,440,894; 3,595,797; 3,929,923; 3,975,278; 3,997,617; and 4,046,703.

Formulating Traction Fluid

5 **[32]** Another aspect of the invention relates to a traction or a CVT fluid comprising the hydrogenated cyclic dimer of α -alkyl styrene as the major component, which may be combined with one or more additives, as needed to improve low temperature viscosity and other desirable properties. Such additives include, but are not limited to, low temperature viscosity control agents, dispersants, detergents, viscosity index modifiers, phosphorus compounds, and friction
10 modifiers. Formulations of a traction or CVT fluid have been taught in the following U.S. patents which are incorporated by reference herein in their entirety: 3,411,369; 3,440,894; 3,595,797; 3,975,278; 4,046,703; 4,521,324; 4,525,290; 4,556,503; 5,422,027; 6,103,673; 6,262,000; 6,337,309; 6,372,696; and 6,451,745. Various additives or components disclosed in the above patents may be used in the traction or CVT fluid.

15 Base Oil

[33] The base oil for a traction fluid in accordance with embodiments of the invention is a hydrogenated cyclic dimer of α -methyl styrene, which is included in an amount of at least 50 percent by weight of the traction fluid. However, in some embodiments, only about 20 wt% to about 50 wt% of the hydrogenated cyclic dimer is present in the traction fluid. On the other hand,
20 in other embodiments, a higher amount, such as at least about 60 wt%, about 70 wt%, about 80 wt%, about 85 wt%, or about 90 wt% is used. Some traction fluids may include up to about 95 wt % to about 99 wt% of the hydrogenated cyclic dimer. In some embodiments, the traction fluids are completely or substantially free of a linear dimer, either hydrogenated or unhydrogenated. However, in other embodiments, a linear dimer may be present up to about 10 to
25 about 20 percent by weight of the traction fluid. In a preferred embodiment, the linear dimer is present in less than about 5 percent by weight of the traction fluid. In some embodiments, hydrogenated trimers are present in the traction fluid, in addition to the hydrogenated dimers. In other embodiments, the traction fluid is completely or substantially free of the trimers or higher oligomers of α -alkyl styrene.

[34] As used herein, the term "substantially free of a linear dimer of the α -alkyl styrene" means that the CVT fluid contains less than about 20 wt.% of a linear dimer of the α -alkyl styrene. In some embodiments, "substantially free of a linear dimer of the α -alkyl styrene" means less than 15 wt.%, less than 10 wt.%, less than 5 wt.%, less than 3 wt.%, less than 1 wt.%, or less than 0.5 wt.%.
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[35] In some embodiments, the CVT fluid is substantially or completely free of any trimer or higher oligomers of the α -alkyl styrene. As used herein, the term "substantially free of trimer or higher oligomers of the α -alkyl styrene" means that the CVT fluid contains less than about 5 wt.% of a linear dimer of the α -alkyl styrene. In some instances, it means less than 1 wt.%, or less than 0.5 wt.%.
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Low-Temperature Viscosity Control Agent

[36] The second component of the traction fluids is a low-temperature viscosity control agent. The low-temperature viscosity control agent (which is to be distinguished from a viscosity index modifier, an optional component described below) is selected from among a variety of materials which are known to be useful for this purpose. The low-temperature viscosity control agent is selected from (a) oligomers or polymers of linear α -olefins of at least 12 carbon atoms, (b) naphthenic oils, (c) synthetic ester oils, or (d) polyether oils, or mixtures thereof. These materials are distinguishable from the base fluids, described above, in that they are generally lower viscosity materials than the base fluid, typically exhibiting a viscosity of up to or less than about $2.5 \times 10^{-6} \text{ m}^2/\text{s}$ (2.5 cSt), preferably about 1.5 to about 2.5, or about 1.8 to about $2.3 \times 10^{-6} \text{ m}^2/\text{s}$ (1.5 to 2.5 or 1.8 to 2.3 cSt) at about 100 °C. These are also materials which typically retain a measure of mobility at low temperatures (e.g., -30 °C) and can serve to reduce the low temperature viscosity of fluids to which they are added. On the other hand, in other embodiments, The low-temperature viscosity control agent can be materials which have a viscosity greater than $2.5 \times 10^{-6} \text{ m}^2/\text{s}$ (2.5 cSt), such as $3.0 \times 10^{-6} \text{ m}^2/\text{s}$ (3 cSt), $4.0 \times 10^{-6} \text{ m}^2/\text{s}$ (4 cSt), $5.0 \times 10^{-6} \text{ m}^2/\text{s}$ (5 cSt), $6.0 \times 10^{-6} \text{ m}^2/\text{s}$ (6 cSt) or higher.
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[37] Polymers and oligomers of linear α -olefins are well known items of commerce. A typical commercial material is Ethylflo™ 162, a $2 \times 10^{-6} \text{ m}^2/\text{s}$ (2 cSt) poly- α -olefin product of

Ethyl Corporation. Preferred materials are those oligomers or polymers of α -olefins containing 12 to 40 carbon atoms, and preferably 16 to 20 carbon atoms. Such materials do not contain a significant fraction of α -olefin monomers of fewer than 12 carbon atoms, that is, less than about 5 percent by weight, preferably less than about 1 percent by weight, and more preferably substantially no such monomers. The description "oligomers or polymers" is used since generally low molecular weight materials are desired, and there is otherwise no clear demarcation between an oligomer and a polymer. Materials as low as dimers (a degree of polymerization of 2) are included. Suitable materials for the present invention typically have a molecular weight range of about 100 to about 1000, preferably about 150 to about 600, and most preferably about 250 to about 600 or, about 250 to about 500 or about 250 to about 400.

[38] Naphthenic oils are well known items of commerce, commonly derived from petroleum. Preferred materials are hydrogenated naphthenic oils, which are also well known. Examples include Hydrocal™ 38 from Calumet Lubricants Company and 40 Pale Oil™ from Diamond Shamrock. Synthetic ester oils suitable for use as low temperature viscosity control agents include esters of polyhydroxy compounds and predominantly monocarboxylic acylating agents; esters of predominantly monohydroxy compounds and polycarboxylic acylating agents; esters of monohydroxy compounds and monocarboxylic acylating agents, and mixtures of the foregoing types. The prefix "poly" in this context indicates at least two hydroxy groups or carboxylic groups, as the case may be. The molecular weight of the esters (as of any of the viscosity control agents) should be sufficiently high that the materials are not objectionably volatile so as to experience significant evaporative loss under operating conditions, while retaining the above-described viscosities. Certain synthetic ester oils and their methods of preparation are disclosed in PCT publication WO 91/13133. Synthetic ester oils are available as Emery™ synthetic lubricant basestocks from Henkel Corporation and as Emkarate™ lubricant basestocks from Imperial Chemical Industries PLC.

[39] Polyether oils suitable for use as a low temperature viscosity control agent include polyalkylene oxides, and in particular, polyethylene oxides, polypropylene oxides, polybutylene oxides, and mixtures thereof. The polyether oil typically has a molecular weight in the ranges suitable for maintaining an appropriate viscosity and non-volatility. Such materials are also well

known items of commerce and are available as Emkarox™ polyalkylene glycols from Imperial Chemical Industries PLC.

[40] As is the case with the base fluid, the low temperature viscosity control agent is often a hydrogenated material. Each of these components preferably contains fewer than about 20%, fewer than about 15%, or more preferably fewer than about 10% molecules containing carbon-carbon unsaturation, and in the most preferred case is substantially free from carbon-carbon unsaturation, that is to say, retaining at most a low level of unsaturation which does not measurably or significantly affect its performance.

[41] The amount of the low temperature viscosity control agent in the traction fluid is preferably that amount suitable to provide a viscosity at -30 °C of a CVT fluid of less than or equal to 100 Pa•s (100,000 cP), such as about 2 to about 100 Pa•s (2,000 to 100,000 cP), preferably about 5 to about 80 or about 70 Pa•s (5,000 to 80,000 or 70,000 cP), and more preferably 10 to 50 Pa•s (10,000 to 50,000 cP). As stated previously, the amount of low temperature viscosity control agent should preferably be about 1 to 20 percent by weight of the traction fluid, preferably about 3 to about 15, and more preferably about 5 to about 10 percent by weight.

Viscosity Index Improvers

[42] To increase the viscosity at higher temperatures, viscosity index improvers are added to the formulation. Generally speaking, there are two types of viscosity modifiers (or viscosity index improvers). One is the relative polar ester-type, such as LUBRIZOL 7671™, which is a long chain ester of maleic anhydride styrene copolymer (see also, LUBRIZOL 7764™ and LUBRIZOL 7783™ which are polymethacrylate copolymers). The other is the non-polar hydrogenated olefin copolymer (OCP) type, such as LUBRIZOL 7075™, (also included are hydrogenated styrene-diene copolymers, such as INFINEUM SV 200™ and INFINEUM SV 150™, etc.) which are amorphous hydrocarbon polymers.

[43] A preferred polar ester-type viscosity modifier is LUBRIZOL™ 7671 made by LUBRIZOL (Wickliffe, OH). LUBRIZOL™ 7671 is a polymethacrylate type thickener and also acts as a pour point depressant for vegetable oils. Other polar ester-type viscosity modifiers

include LUBRIZOL™ 7764, LUBRIZOL™ 7776, LUBRIZOL™ 7785, LUBRIZOL™ 7786, from LUBRIZOL (Wickliffe, OH) which are polymethacrylate copolymer viscosity index improvers.

[44] Polar ester-type viscosity modifiers having similar properties as those in the following table are also useful:

Property	Value
Flash Point, °C	165
Specific Gravity	0.90
Viscosity, cSt	8500 @ 40 °C 1500 @ 100 °C

[45] A preferred non-polar hydrogenated olefin copolymer-type viscosity modifier is the LUBRIZOL 7075™ Series made by LUBRIZOL (Wickliffe, OH). This series is Lubrizol's next generation nondispersant olefin copolymer (OCP) viscosity modifier. Hydrogenated olefin copolymers are the most widely used type of viscosity modifier for passenger car motor oils and heavy-duty diesel engine oils. Developed in the mid-1960s, hydrogenated olefin copolymers differ mainly in molecular weight and the ratio of ethylene to propylene. These polymers effectively minimize viscosity variations over typical engine operating temperatures. They are cost-effective and are suitable for formulating nearly any mainline engine oil. The polymers provide a cost-effective way to meet the latest international and original equipment manufacturer (OEM) specifications for passenger car and heavy-duty diesel engine oils.

[46] Non-polar hydrogenated olefin copolymer-type viscosity modifiers having the following characteristics may also be useful in embodiments:

Property	Value
Flash Point, °C	190
Specific Gravity	0.87
Viscosity, cSt	825 @ 100 °C

[47] LUBRIZOL 7075D™ is a preferred olefin copolymer type viscosity modifier from LUBRIZOL (Wickliffe, OH). Other olefin copolymer type viscosity modifiers include the LUBRIZOL 7070™ series, 7077™ series, 7740™ series; INFINEUM SV140™, SV145™, SV200™, SV205™, SV300™, SV305™, (EXXONMOBIL, TX) and PARATONET™ 8900 series by (CHEVRON,CA).

[48] Ester type viscosity modifiers, different from the polar ester types described above, having the following characteristics may also be useful in embodiments:

Property	Value
Flash Point, °C	161
Specific Gravity	0.90
Viscosity, cSt	20.5 @ 100 °C

[49] The ester type viscosity index improver may be added in an amount from about 0 to about 3.0 wt%, more preferred from about 0.2 to about 2.5 wt%, most preferred from about 0.5 to about 2 wt% and the hydrogenated olefin copolymer type viscosity index improver may be added in an amount from about 0 to about 6.0 wt%, more preferred from about 1 to about 5 wt%, most preferred from about 2 to about 4 wt%.

[50] Other suitable conventional viscosity index improvers, or viscosity modifiers, are olefin polymers, such as polybutene, hydrogenated polymers and copolymers and terpolymers of styrene with isoprene and/or butadiene, polymers of alkyl acrylates or alkyl methacrylates, copolymers of alkyl methacrylates with N-vinyl pyrrolidone or dimethylaminoalkyl methacrylate. These are used as required to provide the viscosity range desired in the finished oil, in accordance with known formulating techniques.

[51] Esters obtained by co-polymerizing styrene and maleic anhydride in the presence of a free radical initiator and thereafter esterifying the copolymer with a mixture of C₄-C₁₈ alcohols, are also useful as viscosity modifying additives. The styrene esters generally are considered to be multi-functional premium viscosity modifiers. The styrene esters in addition to their viscosity-modifying properties also are pour point depressants and exhibit dispersancy properties when the esterification is terminated before its completion leaving some unreacted anhydride or carboxylic acid groups. These acid groups can then be converted to amides by reaction with a primary amine. The co-polymerization of styrene with maleic anhydride creates a copolymer (SMA) which has a higher glass transition temperature than polystyrene and is chemically reactive with certain functional groups. Thus, SMA polymers are often used in blends or composites where interaction or reaction of the maleic anhydride provides for desirable interfacial effects. Some SMA polymers that are commercially available from ROHMAX USA (Horsham, PA) include VISCOPLEX™ 2-

360, VISCOPLEX™ 2-500, VISCOPLEX™ 3-540, VISCOPLEX™ 4-671, and VISCOPLEX™ 6-054.

[52] Another class of suitable viscosity index improvers is polymethacrylate(PMA)-based viscosity modifiers. For example, a suitable viscosity modifier is a copolymer comprising
5 units derived from (a) methacrylic acid esters containing from about 9 to about 25 carbon atoms in the ester group, and (b) methacrylic acid esters containing from about 7 to about 12 carbon atoms in the ester group, said ester groups having 2-(C₁₋₄ alkyl)-substituents, and optionally (c) at least one monomer selected from the group consisting of methacrylic acid esters containing from
10 about 2 to about 8 carbon atoms in the ester group and which are different from methacrylic acid esters (a) and (b), vinyl aromatic compounds, and nitrogen-containing vinyl monomers, with the proviso that no more than about 60% by weight of the esters contain not more than 11 carbon atoms in the ester group. Such a copolymer is disclosed in U.S. Patent No. 6,124,249, which is incorporated by reference herein in its entirety.

[53] Commercial PMA-based viscosity modifiers are available from Lubrizol Corporation under the following trade names: Lubrizol® 7776 - nondispersant polymethacrylate
15 viscosity modifier with pour point depressing properties and an Orbahn Shear Stability Index of 0 to 2; Lubrizol® 7785 - nondispersant polymethacrylate viscosity modifier diluted in vegetable oil for environmentally sensitive applications; Lubrizol® 7786 - nondispersant polymethacrylate viscosity modifier with pour point depressing properties and an Orbahn Shear Stability Index of
20 10; and Lubrizol® 7794 - nondispersant polymethacrylate viscosity modifier with pour point depressing properties and an Orbahn Shear Stability Index of 20.

[54] Another component of the lubricant formulation may be an oil soluble zinc salt. There is no particular restriction on the type of zinc salt; however, it should not be a zinc thiophosphate or dithiophosphate material. While zinc dialkyldithiophosphates (ZDDPs) are
25 widely known in the lubricating art, they should not be present in the CVT fluids except perhaps in small and inconsequential amounts. Indeed, the CVT fluids should be substantially free from any thiophosphate derivatives, in order to provide a formulation which exhibits minimal copper corrosion. In one embodiment, the lubricating formulation is substantially free from compounds of all types containing active sulfur atoms. By "active sulfur atoms" is meant sulfur atoms which are

available (or are sufficiently labile to become available) to react with metal parts of a transmission. Besides elemental sulfur, materials which may contain or may generate active sulfur atoms include common anti-wear agent including sulfurized olefins, thiocarbamates, and dithiocarbamates. By "substantially free" it is meant that the amount of the thiophosphate material is sufficiently low as to have no practically measurable effect on performance of the fluid, with regard to copper corrosion. In numerical terms this would normally correspond to an amount of zinc dialkyldithiophosphate of less than 200 parts per million in the composition, preferably less than 50 or 10 ppm.

[55] Copper corrosion is measured by ASTM standard test number 130. The compositions are formulated to be substantially free from thiophosphate salts, exhibits a copper corrosion rating of 1B or better when tested for 3 hours at 149 °C.

[56] Oil-soluble zinc salts are species which contain at least one hydrocarbyl group of at least 4, and preferably at least 6, carbon atoms. The hydrocarbyl group is generally required in order to provide the required oil solubility, and its particular length or other characteristics may vary depending on the type of zinc salt involved. Suitable zinc salts include zinc phosphates, phosphites, phosphonates, sulfonates, carboxylates, phenates, and salicylates.

[57] As used herein, the term "hydrocarbyl substituent" or "hydrocarbyl group" is used in its ordinary sense, which is well-known to those skilled in the art. Specifically, it refers to a group having a carbon atom directly attached to the remainder of the molecule and having predominantly hydrocarbon character. Examples of hydrocarbyl groups include:

(1) hydrocarbon substituents, that is, aliphatic (e.g., alkyl or alkenyl), alicyclic (e.g., cycloalkyl, cycloalkenyl) substituents, and aromatic-, aliphatic-, and alicyclic-substituted aromatic substituents, as well as cyclic substituents wherein the ring is completed through another portion of the molecule (e.g., two substituents together form a ring);

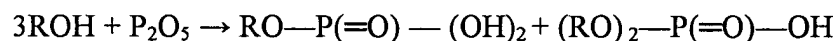
(2) substituted hydrocarbon substituents, that is, substituents containing non-hydrocarbon groups which, in the context of this invention, do not alter the predominantly hydrocarbon substituent (e.g., halo (especially chloro and fluoro), hydroxy, alkoxy, mercapto, alkylmercapto, nitro, nitroso, and sulfoxy);

(3) hetero substituents, that is, substituents which, while having a predominantly hydrocarbon character, in the context of this invention, contain other than carbon in a ring or chain otherwise composed of carbon atoms. Heteroatoms include sulfur, oxygen, nitrogen, and encompass substituents as pyridyl, furyl, thienyl and imidazolyl. In general, no more than two, preferably no more than one, non-hydrocarbon substituent is present for every ten carbon atoms in the hydrocarbyl group; typically, there is no non-hydrocarbon substituents in the hydrocarbyl group.

[58] Hydrocarbyl groups containing active sulfur may be avoided, if desired, to the extent that they may undesirably contribute to copper corrosion.

[59] In one embodiment, the zinc salt is a zinc hydrocarbyl phosphate. The phosphate can be a mono-or dihydrocarbyl phosphate. Each hydrocarbyl groups typically independently contain 1 to 30 carbon atoms, preferably 1 to 24 carbon atoms, more preferably 1 to 12 carbon atoms, provided, as stated above, that at least one hydrocarbyl group contains at least 6 carbon atoms. In a preferred embodiment, each hydrocarbyl is independently an alkyl or aryl group. When any group is an aryl group it typically contains 6 to 24 carbon atoms, more preferably 6 to 18 carbon atoms. Examples of hydrocarbyl groups include a butyl, amyl, hexyl, octyl, oleyl or cresyl, with octyl and cresyl being preferred.

[60] The zinc hydrocarbyl phosphates can be prepared by reacting phosphorus acid or anhydride, preferably phosphorus pentoxide, with an alcohol at a temperature of 30 °C to 200 °C, preferably 80 °C to 150°C, followed by neutralization with a zinc base. The phosphorus acid is generally reacted with the alcohol in a ratio of about 1:3.5, preferably 1:2. The product of such a reaction typically comprises a mixture of monohydrocarbyl and dihydrocarbyl zinc phosphates, typically being present in a relative ratios of about 1:1, or more generally, 2:1 to 1:2 or 3:1 to 1:3. Mixtures of about 1:1 monohydrocarbyl: dihydrocarbyl materials can be prepared by the simple stoichiometric reaction of alcohol with P₂O₅:



[61] The alcohol can be any of the commercially available alcohols having an appropriate chain length, or mixtures of such alcohols. The alcohols can be aliphatic,

cycloaliphatic, aromatic, or heterocyclic, including aliphatic-substituted cycloaliphatic alcohols, aliphatic-substituted aromatic alcohols, aliphatic-substituted heterocyclic alcohols, cycloaliphatic-substituted aliphatic alcohols, cycloaliphatic-substituted aromatic alcohols, cycloaliphatic-substituted heterocyclic alcohols, heterocyclic-substituted aliphatic alcohols, heterocyclic-substituted cycloaliphatic alcohols, and heterocyclic-substituted aromatic alcohols. The alcohols may contain non-hydrocarbon substituents of a type which do not interfere with the reaction of the alcohols with the phosphorus compound. The alcohols can be monohydric alcohols such as methanol, ethanol, isooctanol, 2-ethylhexanol, dodecanol, and cyclohexanol. Alternatively, the alcohols can be polyhydric alcohols, such as alkylene polyols such as ethylene glycols, including di-, tri- and tetraethylene glycols; propylene glycols, including di-, tri- and tetrapropylene glycols; glycerol; and the like. Also useful alcohols are mixed C₁₈-C₂₈ primary alcohols having mostly, on an alcohol basis, C₂₂ alcohols. A variety of mixtures of monohydric fatty alcohols derived from naturally occurring triglycerides and ranging in chain length of from C₈ to C₁₈ are also useful, and are available from various sources including Procter & Gamble Company.

[62] Another category of zinc salts includes the zinc carboxylates. These can be seen as the neutralization product of a zinc base and a carboxylic acid. As before, the carboxylic acid should contain at least 6 carbon atoms, to provide appropriate solubility. The carboxylic acids can be aliphatic or aromatic, mono- or polycarboxylic acids (or acid-producing compounds). These carboxylic acids include lower molecular weight carboxylic acids as well as higher molecular weight carboxylic acids (e.g. having more than 8 or more carbon atoms). Usually, in order to provide the desired solubility, the number of carbon atoms in a carboxylic acid should be at least about 8, e.g., 8 to 400, preferably 10 to 50, and more preferably 10 to 22.

[63] Carboxylic acids include saturated and unsaturated acids. Examples of useful acids include dodecanoic acid, decanoic acid, tall oil acid, 10-methyl-tetradecanoic acid, 3-ethyl-hexadecanoic acid, and 8-methyl-octadecanoic acid, palmitic acid, stearic acid, myristic acid, oleic acid, linoleic acid, behenic acid, hexatriacontanoic acid, tetrapropylenyl-substituted glutaric acid, polybutenyl-substituted succinic acid derived from a polybutene (average Mn = 200-1500), polypropenyl-substituted succinic acid derived from a polypropene, (average Mn = 200-1000), octadecyl-substituted adipic acid, chlorostearic acid, 12-hydroxystearic acid, 9-methylstearic acid,

dichlorostearic acid, ricinoleic acid, lesquerellic acid, stearyl-benzoic acid, eicosanyl-substituted naphthoic acid, dilauryl-decahydronaphthalene carboxylic acid, mixtures of any of these acids, their alkali and alkaline earth metal salts, their ammonium salts, their anhydrides, or their esters or triglycerides. A preferred group of aliphatic carboxylic acids includes the saturated and
5 unsaturated higher fatty acids containing from about 12 to 30 carbon atoms. Other acids include aromatic carboxylic acids including substituted and non-substituted benzoic, phthalic and salicylic acids or anhydrides, most especially those substituted with a hydrocarbyl group containing about 6 to 80 carbon atoms. Examples of suitable substituent groups include butyl, isobutyl, pentyl, octyl, nonyl, dodecyl, and substituents derived from the above-described polyalkenes such as
10 polyethylenes, polypropylenes, polyisobutylenes, ethylene-propylene copolymers, and oxidized ethylene-propylene copolymers.

[64] An especially preferred zinc carboxylate is zinc oleate, which can be prepared by the neutralization of oleic acid by a basic zinc compound. Another zinc carboxylate is zinc salicylate.

15 [65] The zinc compound can be a simple (neutral) salt, generally formed by straightforward stoichiometric acid-base neutralization of the acid with a zinc base such as zinc oxide or zinc hydroxide. The zinc salt can also be an overbased salt. Alternatively, the zinc salt can be a basic salt, in which one equivalent of a zinc base is reacted with somewhat less than one equivalent of acid, as described, for instance, in U.S. Pat. No. 5,110,488 (columns 9 and 10). An
20 example of such a material is a slightly "over-zinc-ed" oleate, that is, $Zn_4Oleate_3O_1$. This is a species of overbased materials in general, which are well known to those skilled in the art and are generally disclosed in numerous patents such as U.S. Pat. No. 3,492,231 and especially the references cited therein.

[66] The amount of the oil-soluble zinc salt should be sufficient to impart an increased
25 steel-on-steel dynamic coefficient of friction for the formulation of at least 0.125, preferably 0.125 or 0.127 to 0.150, more preferably 0.130 to 0.140 or 0.135. The corresponding static coefficient of friction is 0.14 to 0.2. The coefficients of friction are measured at 110 °C by ASTM G-77. The coefficient of friction of the formulation is improved, that is, increased over that of the same composition without the zinc salt.

[67] The preferred amount of the oil soluble zinc salt, differently stated, is 0.05 to 1.0 percent by weight of the lubricant formulation, preferably 0.2 to 0.5 weight percent. The zinc salt preferably contributes up to 0.15 weight percent zinc to the formulation, more preferably 0.01 to 0.1 weight percent.

5 Other Additives

[68] The fluid used in embodiments of the invention may typically contain one or more additional additives suitable for use in a continuously variable transmission or an automatic transmission fluid (ATF). Such additional materials include other friction modifiers; and antioxidants, including hindered phenolic antioxidants, secondary aromatic amine antioxidants,
10 oil-soluble copper compounds, and phosphorus-containing antioxidants. Other components include metal deactivators such as tolyltriazole, benzotriazole, and the methylene-coupled product of tolyltriazole and amines such as 2-ethylhexylamine. Such metal deactivators can also be useful in adjusting the metal-to-metal friction in push belt CVTs. Other components can include seal swell compositions, such as isodecyl sulfolane (that is, isodecyl-3-sulfolanyl ether), which are
15 designed to keep seals pliable. Also permissible are pour point depressants, such as alkyl-naphthalenes, polymethacrylates, vinyl acetate/fumarate or /maleate copolymers, and styrene/maleate copolymers. Also included can be corrosion inhibitors, dyes, fluidizing agents, antifoam agents, dispersants, detergents, and anti-wear agents. These optional materials are known to those skilled in the art, are generally commercially available, and many are described in
20 greater detail in United States Patent No. 6,251,840. Each of these materials may be present in conventional and functional amounts.

[69] Detergents and dispersants of the types discussed in United States Patent No. 6,372,696 patent are known in the lubrication art and reference may be made to the patent for additional information. They are selected to improve the durability of the traction fluid and are
25 generally present in amounts of up to about 20 wt %.

[70] Other potential additives which may be present in traction fluids are phosphorus compounds. It is understood by those skilled in the art that the additives which are used in traction fluids may include any or all of those mentioned above. They are chosen to optimize the

performance of the traction fluid considering both performance and cost. As will be seen in the example, the additives can significantly affect the viscosity and traction coefficient.

[71] The composition of embodiments of the invention is normally supplied as a fully formulated lubricant or functional fluid, or initially prepared as a concentrate. In a concentrate, the relative amounts of the various components are generally about the same as in the fully formulated composition, except that the amount of oil of lubricating viscosity is decreased by an appropriate amount. The absolute percentage amounts of the remaining components are correspondingly increased. Thus, when the concentrate is added to an appropriate amount of oil, the final formulation of the invention is obtained. A typical concentrate of the invention may contain, for instance, 0.5 to 20 weight percent of the zinc salt, that is, about 10 times the concentration typically used in a final blend.

Measurement of Traction Coefficient

[72] The traction coefficient is determined generally as disclosed in U.S. Patent No. 3,975,278 and is a well-known measurement. In this method, coefficient of traction is determined on a rolling disk machine. This machine is designed to predict the performance of a fluid in variable speed drives and comprises two hardened steel rollers which may be loaded one against the other and driven at any required speed. The fluid is introduced between the rollers and the relationships between applied load, roller surface speeds, relative sliding speed between the two rollers, and torque transmitted from one roller to the other through the contact between them are a measure of the potential performance of the fluid in a variable speed drive. Literature references on this rolling disk machine include M. A. Plint [Proceedings of the Inst. of Mech. Engrs., Vol. 180, pp 225, 313 (1965-66)]; "The Lubrication of Rollers, I" by A. W. Crook [Phil. Trans. A 255, 281 (1963a)], which are incorporated by reference herein in their entirety. In addition, the traction coefficient can also be measured by a four-roller machine described in a SAE technical paper 2002-01-1696, entitled "Development of Toroidal Traction Drive CVTF for Automobile" by Toru Matsuoka, Noboru Ishida, Shinichi Komatsu, and Mitsuo Matsuno of Nippon Mitsubishi Oil Corporation, which is incorporated by referenced herein in its entirety.

[73] To carry out the testing, a Mini Traction Machine (MTM) test system from PCS Instruments, 78 Stanley Gardens, London W3 7SZ, UK, can be used. The test includes evaluating

the fluid behavior in an EHD contact formed between a polished 19.1 mm (3/4 inch) steel ball and a 46 mm diameter steel disk, each independently driven to produce a sliding/rolling contact, lubricated with the test specimen (each sample being about 30 g). Testing is carried out at a Hertz contact pressure of 1.25 GPa. The temperature of the test oil at the inlet of the contact is continuously measured and controlled to 100 °C, and the system given sufficient time to thermally stabilize. Rolling speed is maintained at 2.5 m/s. A slide to roll ratio continuously varying from 0% to 10% is achieved by changing the surface speeds of both specimens simultaneously. Traction force is continuously measured during each test, and traction coefficient is calculated therefrom. Traction coefficient, f_t , is defined by:

$$f_t = F_t / P_n$$

where F_t is the measured tangential or tractive force exerted between the members and P_n is the normal load or contact force between the members.

[74] The following examples are presented to exemplify embodiments of the invention. All numerical values are approximate. When numerical ranges are given, it should be understood that embodiments outside the stated ranges may still fall within the scope of the invention. Specific details described in each example should not be construed as necessary features of the invention.

Example 1

[75] A 1.0 cm diameter, 5 cm long vertical steel column, wrapped with a heating tape and thermal couples inserted inside and outside the column to monitor the temperature, was connected to a pump with a Tygon® tubing. The column was filled with 6 grams of Amberlyst 15 (Rohm & Haas). Neat α -methylstyrene (i.e. without solvents) was pumped upward into the column. The product is collected at the other end of the column, and subjected to GC analysis. The components of product at various residence times and temperatures are given in the table below. An C-13 NMR analysis reveals the product is a cyclic dimer of α -methylstyrene, 1-phenyl-1,3,3-trimethylindane. Therefore, it was concluded that α -methyl styrene has been initially dimerized to a linear dimer, 2,4-diphenyl-4-methyl-1-pentene or the corresponding 2-pentene isomer. The linear dimer further contacts the catalyst while traveling through the column and an intramolecular Friedel-Crafts alkylation occurs to give the cyclic dimer. The process did not

involve any solvent or require an aqueous wash. The catalyst was found still active, even after one liter of α -methylstyrene had been passed through the column. The conversion of monomer to polymer was substantially 100%. At 120°C and a high pumping speed, the product gives almost exclusively the cyclic dimer, 1-phenyl-1,3,3-trimethylindane. C-13 NMR: 151.86 ppm, 150.68 ppm, 148.39 ppm, 127.70 ppm, 126.93 ppm, 126.38 ppm, 125.20 ppm, 124.70 ppm, 122.25 ppm, 77.52 ppm, 76.88 ppm, 76.25 ppm, 58.95 ppm, 50.49 ppm, 42.55 ppm, 30.63 ppm, 30.40 ppm, and 30.10 ppm.

TRIAL #	RESIDENCE TIME (MINUTES)	SKIN TEMP., °C	CYCLIC DIMER	LINEAR DIMER	TRIMER
1	48	31	74%	18%	8%
2	15	69	93%	5%	2%
3	29	83	90%	6%	4%
4	15	120	96%	3%	1%
5	59	119	94%	5%	1%

Example 2

[76] The product collected from the column in Trial 4 of Example 1 was completely hydrogenated with 900 psi (6205 kPa) of H₂ at 195°C for 24 hours in the presence of 2% Pd on active carbon as a catalyst. After filtering out the catalyst, the hydrogenated product was ready to use as continuously variable transmissions (CVT) fluid. The pure hydrogenated cyclic dimer, 1-cyclohexyl-1,3,3-trimethylindane, is obtained by further distillation under vacuum, boiling point at 125° - 140°C/0.5 mm Hg; kinematic viscosity 3.9 cSt at 100°C; 22.3 cSt at 40°C C-13 NMR: 53.2 ppm, 50.69 ppm, 48.82 ppm, 45.60 ppm, 44.87 ppm, 39.79 ppm, 31.14 ppm, 28.3-24.03 ppm (multi-peaks), and 20.37 ppm., as compared to C-13 NMR of hydrogenated linear dimer, 2,4-dicyclohexyl-4-methylpentane, 44.22 ppm, 42.42 ppm, 41.32 ppm, 32.62 ppm, 30.36 ppm, 27.52 ppm, 25.57 ppm, 24.45-23.86ppm (multi-peaks), 22.04 ppm, 21.94 ppm, and 15.95 ppm.

Example 3

[77] The traction coefficient was measured by Mini Traction Machine (MTM), manufactured by PCS Instruments at 78 Stanley Gardens, London, England W# 7SZ. The test conditions are briefly described as follows: Both ball and disc speeds are 1 m/sec under no load. Once temperature is equilibrated at 50°C, a 30 N load (~0.88 Gpa) is applied. Slide roll ratio is

increased stepwise in increments of 1 from 0 to 50. The traction coefficient against slide/roll ratio is recorded, and the traction coefficient is read at end of slide/roll ratio of 50%.

[78] The product of Example 2 containing 95% of the hydrogenated cyclic dimer was measured to have a traction coefficient of 0.1062. After purification to remove the trimer of α -methyl styrene the traction coefficient for substantially pure 1-cyclohexyl -1,3,3-trimethylhydriindane was 0.1093. By contrast, a sample of the linear dimer of α -methyl styrene was hydrogenated to 2,4-dicyclohexyl-4-methyl pentane, and measured to have a traction coefficient of 0.1048.

Example 4

[79] In several experiments, traction fluids were formulated to include one or more of an additional base oil, a viscosity index improver, and a low temperature viscosity control agent. In Table 1 below, Emkarate 1130, a low temperature viscosity control agent from Imperial Chemical Industries was added in varying amounts to the hydrogenated cyclic dimer of α -methyl styrene.

Table 1

Formulation				Physical Properties	
Trial	Example 2, wt%	Emkarate 1130, wt%	Kin. Vis @100°C, cSt	Kin. Vis @40°C, cSt	Traction Coefficient
1	95	5	3.74	19.63	0.10515
2	90	10	3.76	20.6	0.10221
3	80	20	3.76	19.7	0.09524

[80] As can be seen, the viscosity at above ambient temperatures was not adversely affected, but the traction coefficient was decreased as the amount of the Emkarate 1130 was increased.

[81] In a second experiment reported in Table 2 a secondary base oil, PAO4, a 4 cSt poly (α -olefin) synthetic hydrocarbon, was added to hydrogenated cyclic dimer of α -methyl styrene and a viscosity index improver, Lz7075, an OCP-type VI improver from Lubrizol was added.

Table 2

Formulation				Physical Properties		
Trial	Example 2, wt%	PAO 4, wt%	Lz 7075, wt%	Kin. Vis @100°C, cSt	Brookfield Vis. @-30°C	Traction Coefficient
1	80	20	0	3.57	20,800	0.09251
2	94	0	6	6.79	314,500	0.10293
3	94	6	0	3.63	123,400	0.10329
4	64	30	6	6.1	11,270	0.08045
5	70	30	0	3.54	6,820	0.08367

[82] As can be seen from the results, the secondary base oil reduced the viscosity and the traction coefficient. Adding the VI index improver increased the viscosity and reduced the traction coefficient below that measured with the cyclic dimer alone. Reducing the amount of the secondary base oil in the absence of the VI improver improved the viscosity and traction coefficient (Trial 3 relative to Trial 1). In Trial 4, adding a substantial fraction of the secondary base oil plus the VI improver increased the viscosity at 100°C, but reduced the viscosity at -30°C, while the traction coefficient was reduced. In Trial 5, omitting the VI improver reduced viscosity and increased the traction coefficient relative to Trial 4.

[83] In a third experiment, the effect of all three additives was explored, except that the type of viscosity index improver was changed. As can be seen from Table 3 below, the viscosity was substantially constant except for Trial 4 where the VI improver was omitted and the viscosity was reduced.

Table 3

Formulation				Physical Properties			
Trial	Example 2, wt%	Emkarate 1130, wt%	PAO 4, wt%	Lz 7785, wt%	Kin. Vis @100°C, cSt	Kin. Vis @40°C, cSt	Brookfield Vis. @-30°C
1	90	0	8	2	4.78	27.1	48,800 cP
2	90	8	0	2	4.67	26.4	46,000 cP
3	95	4	0	11	4.7	26.9	46,400 cP
4	95	3	2	0	3.68	20.8	38,800 cP
Emkarate 1130: di(decyl) sebacate (synthetic di-ester) PAO4: 4 cSt poly(α -olefin) (synthetic hydrocarbon base oil) Lz 7075: Lubrizol OCP-type VI improver Lz 7785: Lubrizol PMA-type VI improver							

TABLE 4

		Formulation			Physical Properties	
Trial	Example 2, wt%	PAO 2, wt%	Kin. Vis @100°C, cSt	Kin. Vis @40°C, cSt	Brookfield Vis.@-30°C, cP	Traction Coefficient
6	80	20	3.1	14.8	10740	0.08938
7	0	0	5.5	114	42050	0.10485
8	0	0	3.4	29	14740	0.09128
PAO2: 2 cSt poly(α -olefin) (synthetic hydrocarbon base oil) Trial 7: Commercial CVT Fluid: Santotrac 50 Trial 8: Commercial CVT Fluid: Santotrac 2000						

[84] As demonstrated above, embodiments of the invention provide a CVT fluid that has a traction coefficient comparable to commercial CVT fluid but has improved low temperature performance, as shown by the Brookfield Viscosity at -30 °C. As heretofore stated, the CVT fluid is excellent with respect of flowability at low temperatures, having a relatively high traction coefficient in a wide temperature and range from room temperature to high temperatures besides having a low viscosity, producing insignificant churning loss and thus achieving high transmission efficiency. Therefore, fuel economy should be improved by the CVT fluid. The process of making the hydrogenated dimer of α -alkyl styrene is relatively simple and can be easily implemented. Therefore, the process is cost-effective. Other properties and advantages are apparent to those skilled in the art.

[85] While the invention has been described with respect to a limited number of embodiments, the specific features of one embodiment should not be attributed to other embodiments of the invention. No single embodiment is representative of all aspects of the inventions. In some embodiments, the compositions may include numerous compounds not mentioned herein. In other embodiments, the compositions do not include, or are substantially free of, any compounds not enumerated herein. Variations and modifications from the described embodiments exist. The method of making the CVT fluid is described as comprising a number of acts or steps. These steps or acts may be practiced in any sequence or order unless otherwise indicated. Moreover, it is known that some of the materials described above may interact in the final formulation, so that the components of the final formulation may be different from those that are initially added. For instance, metal ions (of, e.g., a detergent) can migrate to other acidic sites of other molecules. The products formed thereby, including the products formed upon employing

the composition of the invention in its intended use, may not susceptible of easy description. Nevertheless, all such modifications and reaction products are included within the scope of the invention; the invention encompasses the composition prepared by admixing the components described above. The appended claims intend to cover all those modifications and variations as
5 falling within the scope of the invention.

[86] What is claimed is: